Thermal Control Coating Charging Tests
for the
Europa Clipper Mission

Todd A. Schneider, Jason A. Vaughn, Erin G. Hayward, and Kenneth H. Wright Jr.
NASA Marshall Space Flight Center (MSFC)
Teri Juarez, Nora Low, Lynn Long, Wousik Kim, James Chinn, and Allen Andersen
NASA Jet Propulsion Laboratory (JPL)

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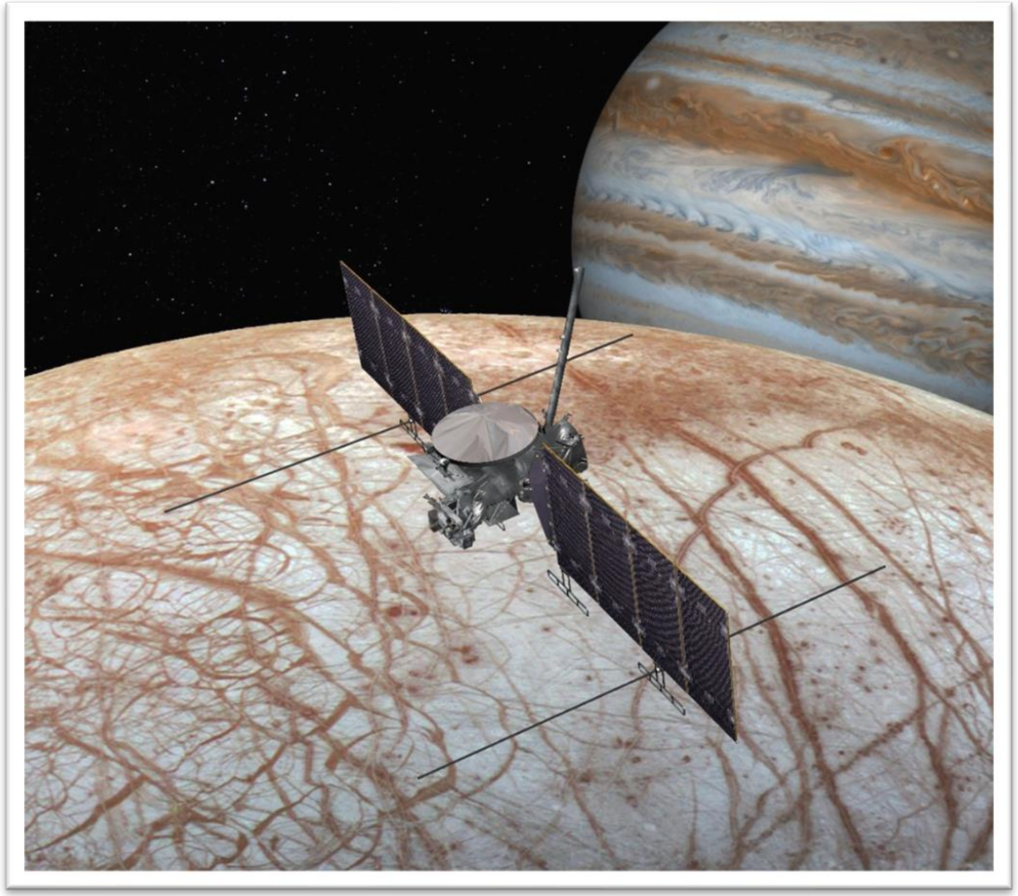
Introduction

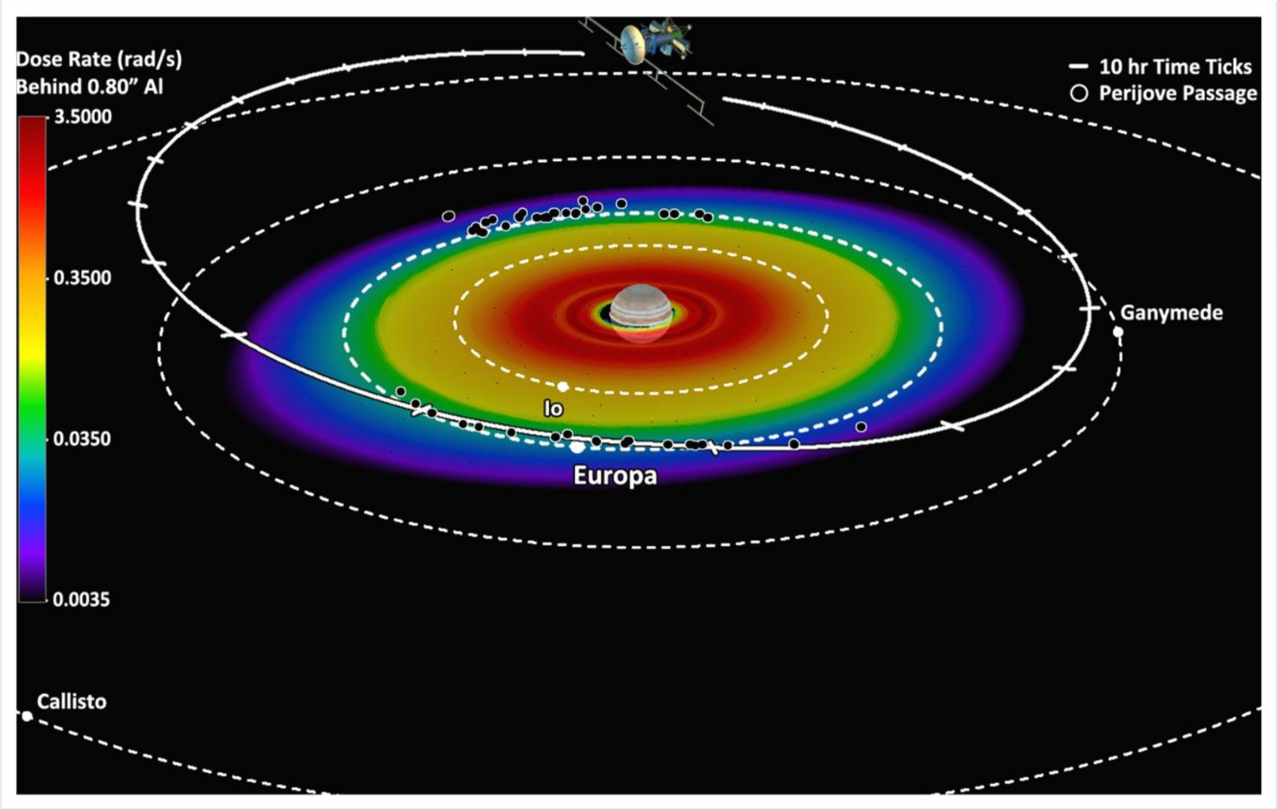
- Europa Clipper Mission
  - Europa is a moon of Jupiter
- The Jovian Environment
  - Jupiter’s large magnetic field creates a high-radiation environment as well low energy plasma charging environments
  - Jupiter’s distance from the Sun ~5 AU
    - Low solar energy yields a cold environment
- Thermal Control Coating (TCC)
  - White and Black coatings needed
    - Local variations in heating/cooling needs
    - Globally, the spacecraft is in a cold environment
  - All the coatings must have low resistivity to reduce charge build-up and lower the probability of Electrostatic Discharge (ESD) events occurring
    - Spacecraft instrument sensitivities are quite high, increasing susceptibility to noise pickup from ESD events
      - Magnetometer systems are a good example of sensitive detectors



Credit: NASA/JPL-Caltech

Typical Test Conditions

Credit: NASA/JPL-Caltech



Thermal conditioning specimens prior to charging tests:

1. Pre-condition vacuum bake, 100C, 89 hours
2. In-situ vacuum bake, 100C, 10 hours

- Highly elliptical orbit to minimize total radiation dose
  - Typical 40-hour encounter phase in charging environments during Europa surveys
  - A compromise for lab testing was to use a four times (4x) flux for 10-hours
  - For sample thickness > 2 mils: Electron flux of 0.5 nA/cm^2
  - For sample thickness < 2 mils: Electron flux of 0.72 nA/cm^2
- Focus on surface charging for the Thermal Control Coatings
  - Coatings tend to be thin but can cover large areas
  - Electron Beam Energy = 60 keV (on sample)
- Screening test at Room Temperature (RT)
  - 4-hours at RT
- Principal tests at -170 C (cryogenic)
  - 10-hours at -170 C
- 1 GHz bandwidth oscilloscope

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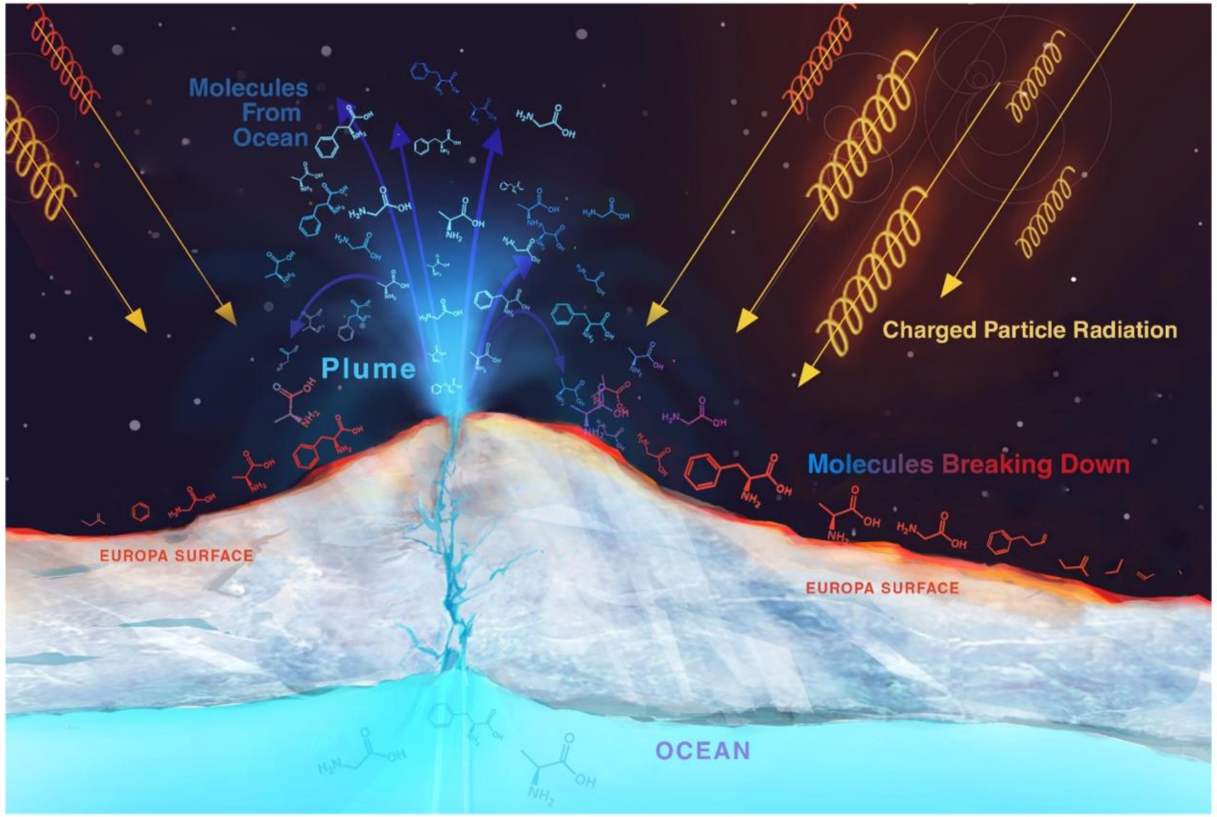
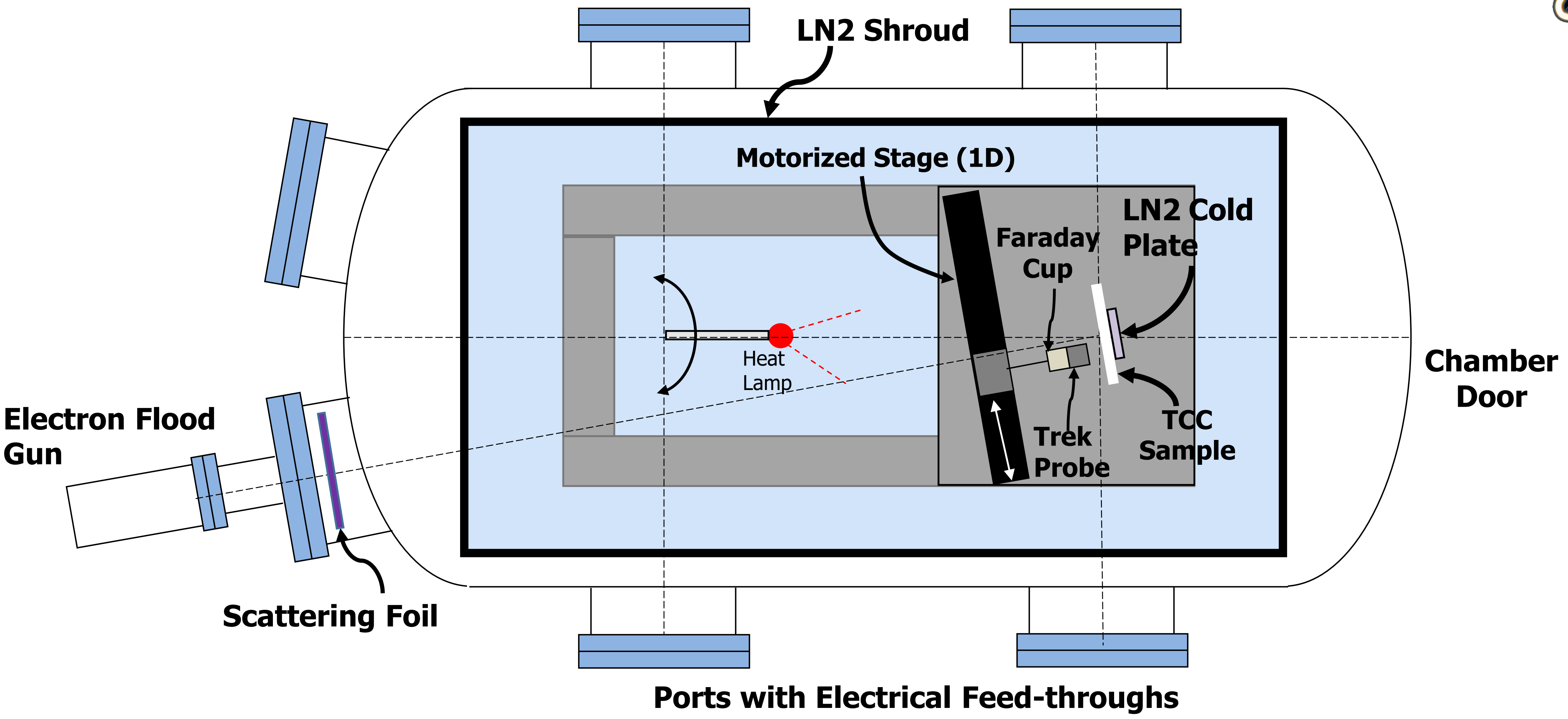
Sample Sizes and Area Scaling

- Typically, the coatings were applied to a thin Aluminum substrate
- The original test samples were 3.5-inch x 6.0-inch (8.9 cm x 15.2 cm)
- When a coating exhibited significant charging and/or large magnitude ESD events, it was removed from consideration for use on the spacecraft
- If a coating showed modest ESD activity, or low magnitude peak currents, then samples were created in two distinct sizes to allow a check on peak ESD current magnitude as a function of coating area
- Two sample sizes provided:
  - 4.0-inch x 4.0-inch (10.2 cm x 10.2 cm)
  - 8.5-inch x 8.5-inch (21.6 cm x 21.6 cm)

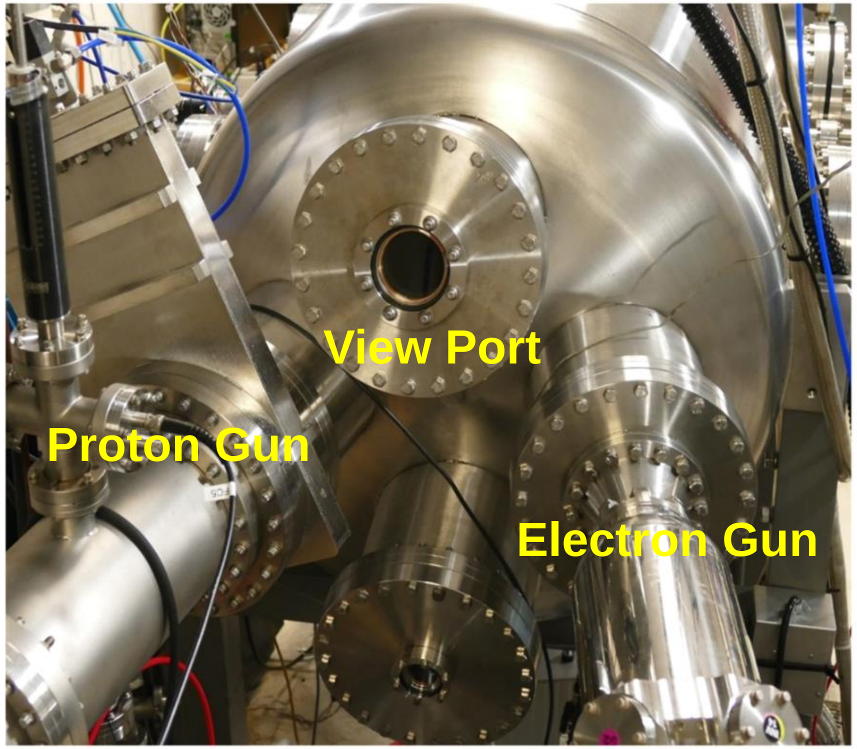


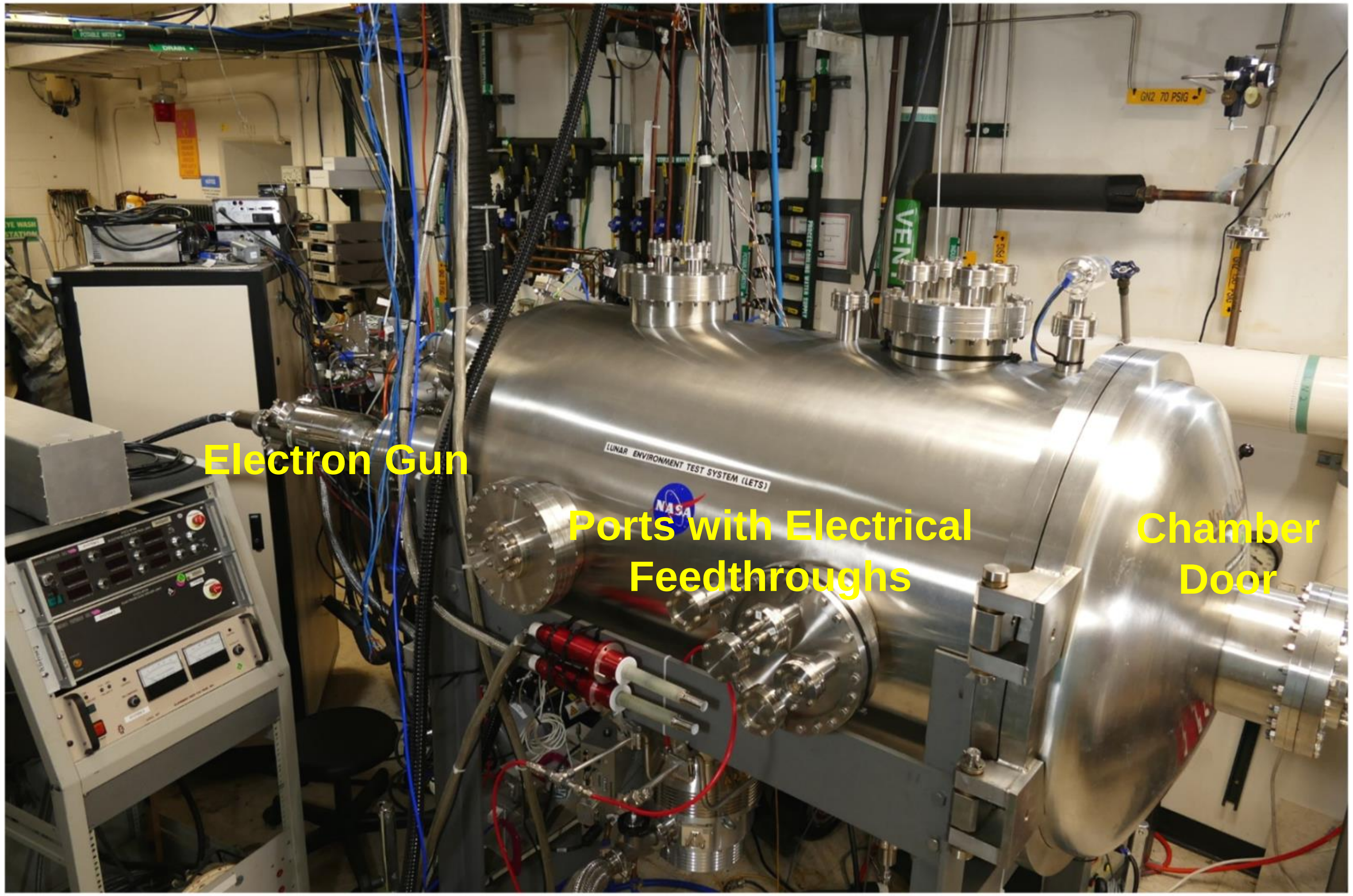
Credit: NASA/JPL-Caltech

Top View Schematic of Vacuum Chamber Setup



Vacuum Vessel Test Chamber



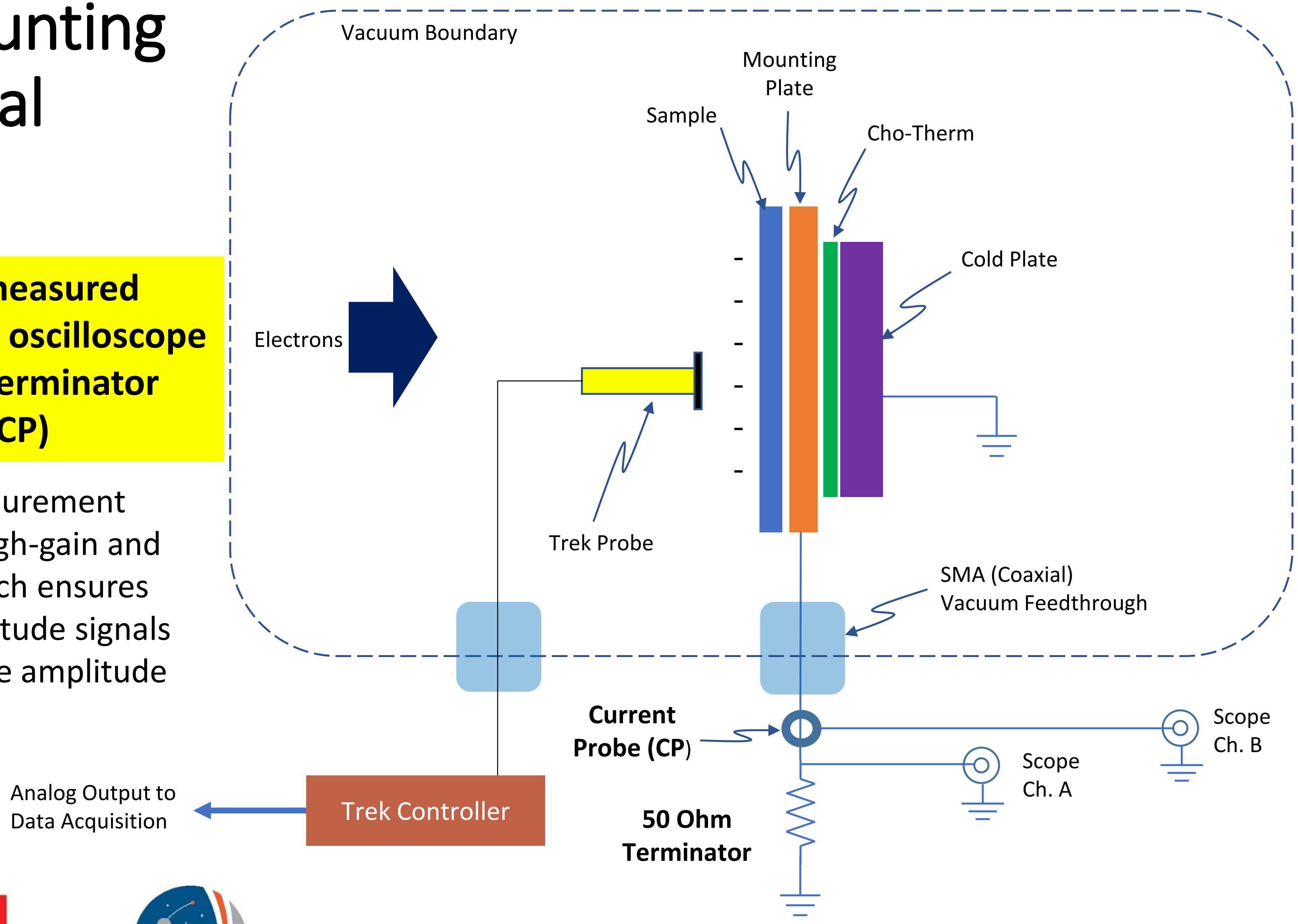


Credit for both pictures:
NASA/MSFC/T. Schneider

Sample Mounting and Electrical Schematic

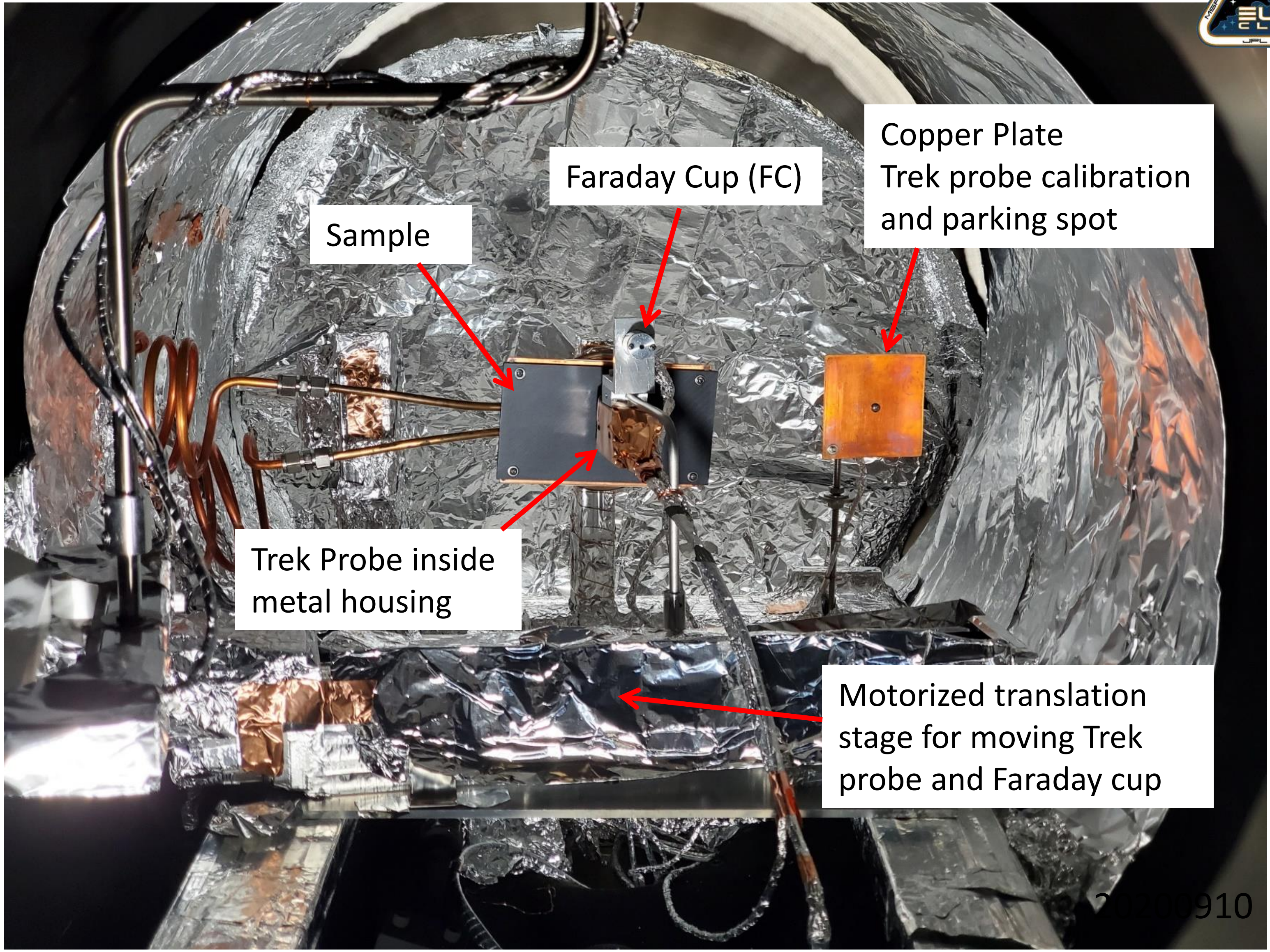
ESD current signal measured simultaneously by 2 oscilloscope channels: 50-Ohm Terminator and Current Probe (CP)

Redundant signal measurement allows for dedicated high-gain and low-gain channels, which ensures resolution of low amplitude signals without saturating large amplitude signals



Original Setup
3.5-inch x 6-inch (8.9 cm x 15.2 cm) Sample Size

Trek probe allows for non-contact measurement of the surface potential. The probe is constructed with an electrically insulating shaft; therefore, it must be housed in a metal shield to avoid charging and ESD generation.

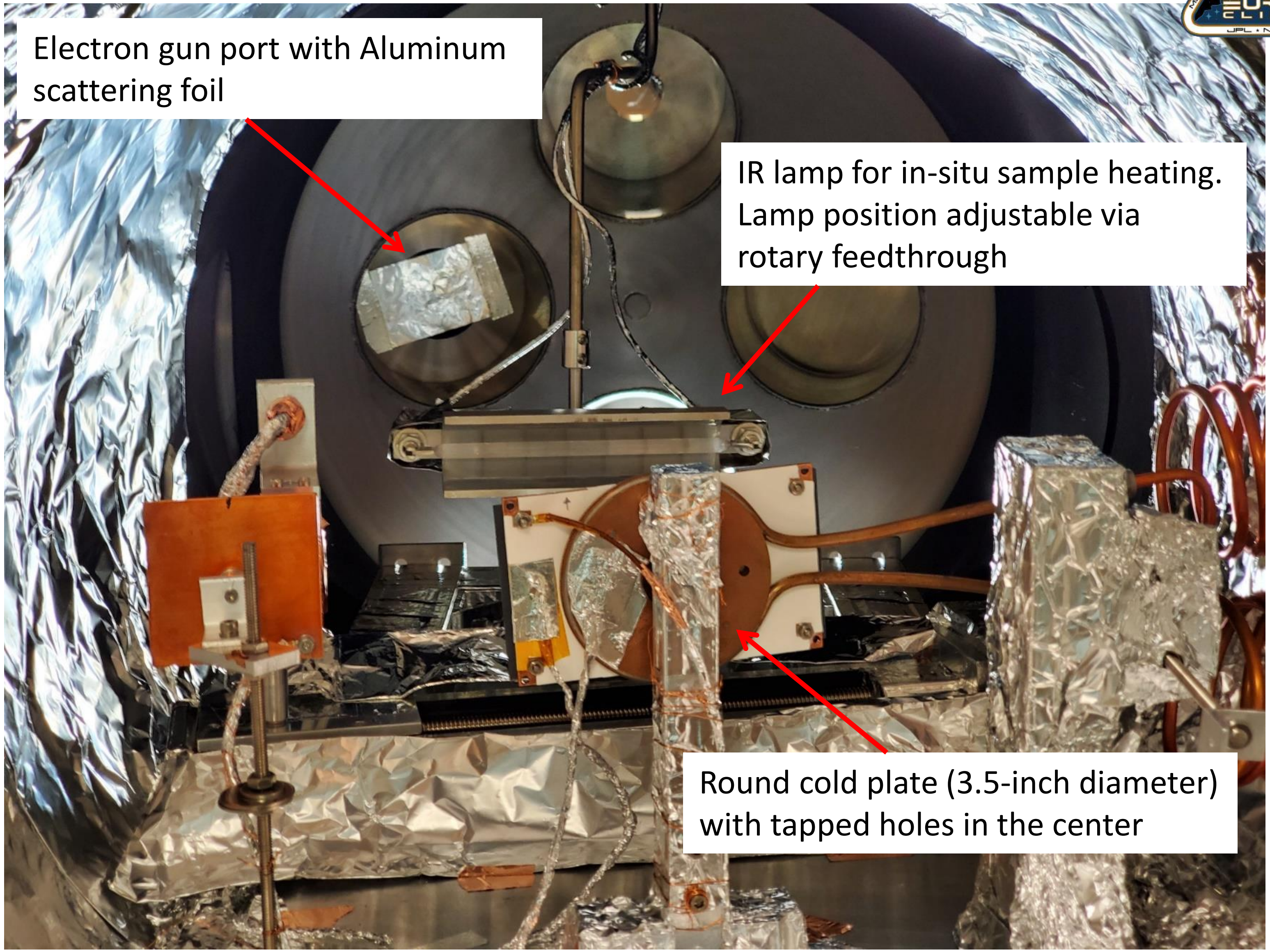


Credit: NASA/MSFC/T. Schneider

Original Setup 3.5-inch x 6-inch (8.9 cm x 15.2 cm) Sample Size View from Chamber Door

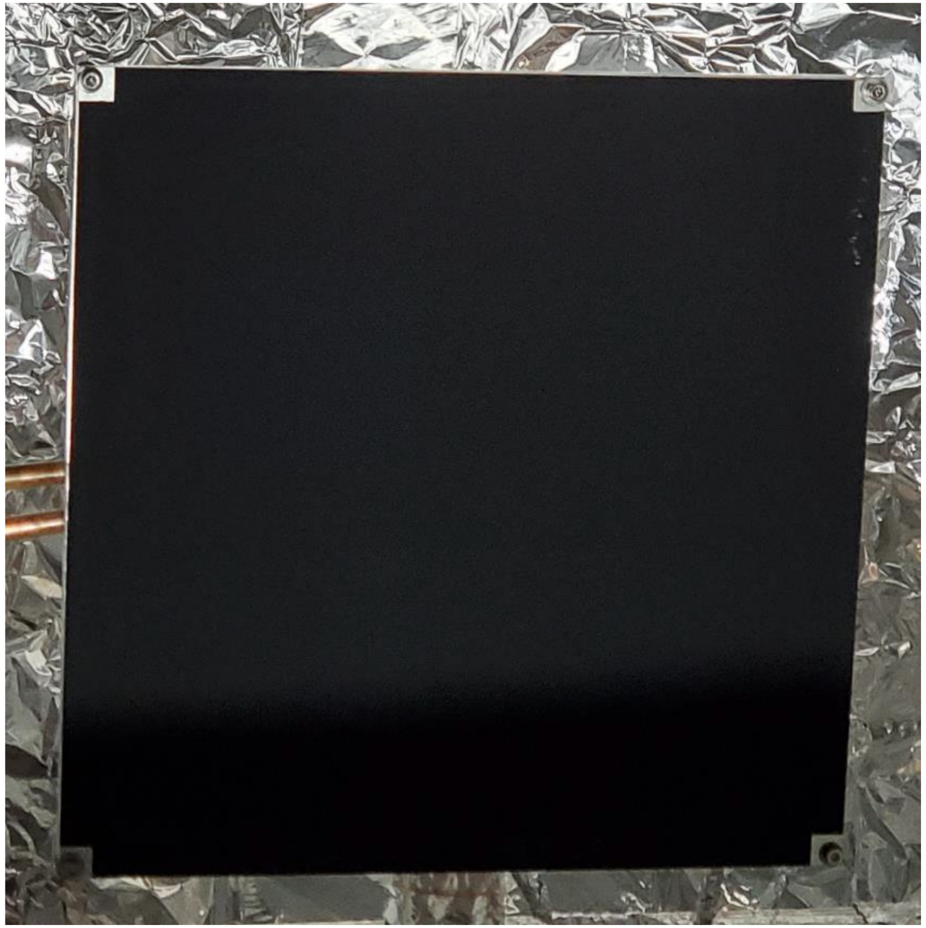
Sample cooling required a cold plate as well as liquid nitrogen (LN2) cold shroud

Credit: NASA/MSFC/T. Schneider

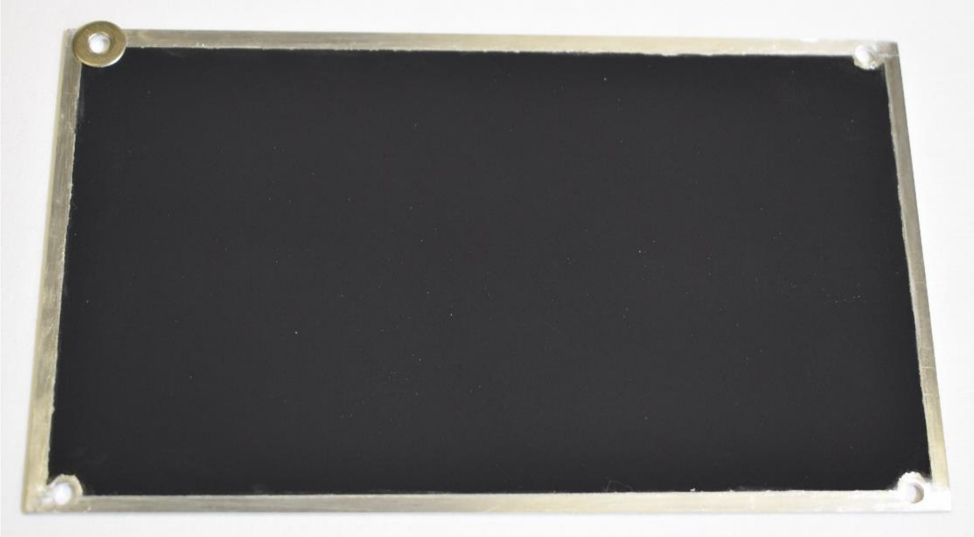


Samples

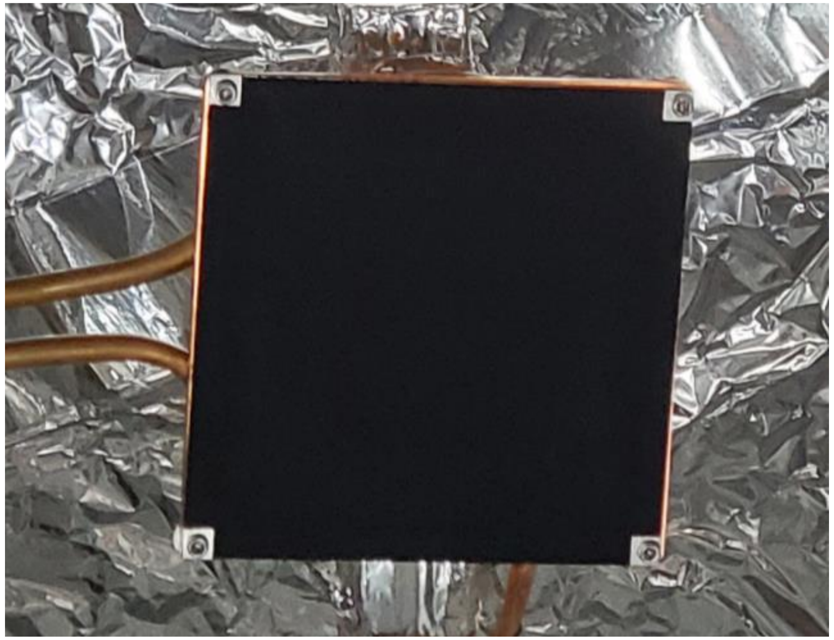
Credit for all pictures: NASA/MSFC/T. Schneider



8.5-inch x 8.5-inch (21.6 cm x 21.6 cm)



3.5-inch x 6.0-inch (8.9 cm x 15.2 cm)



4.0-inch x 4.0-inch (10.2 cm x 10.2 cm)

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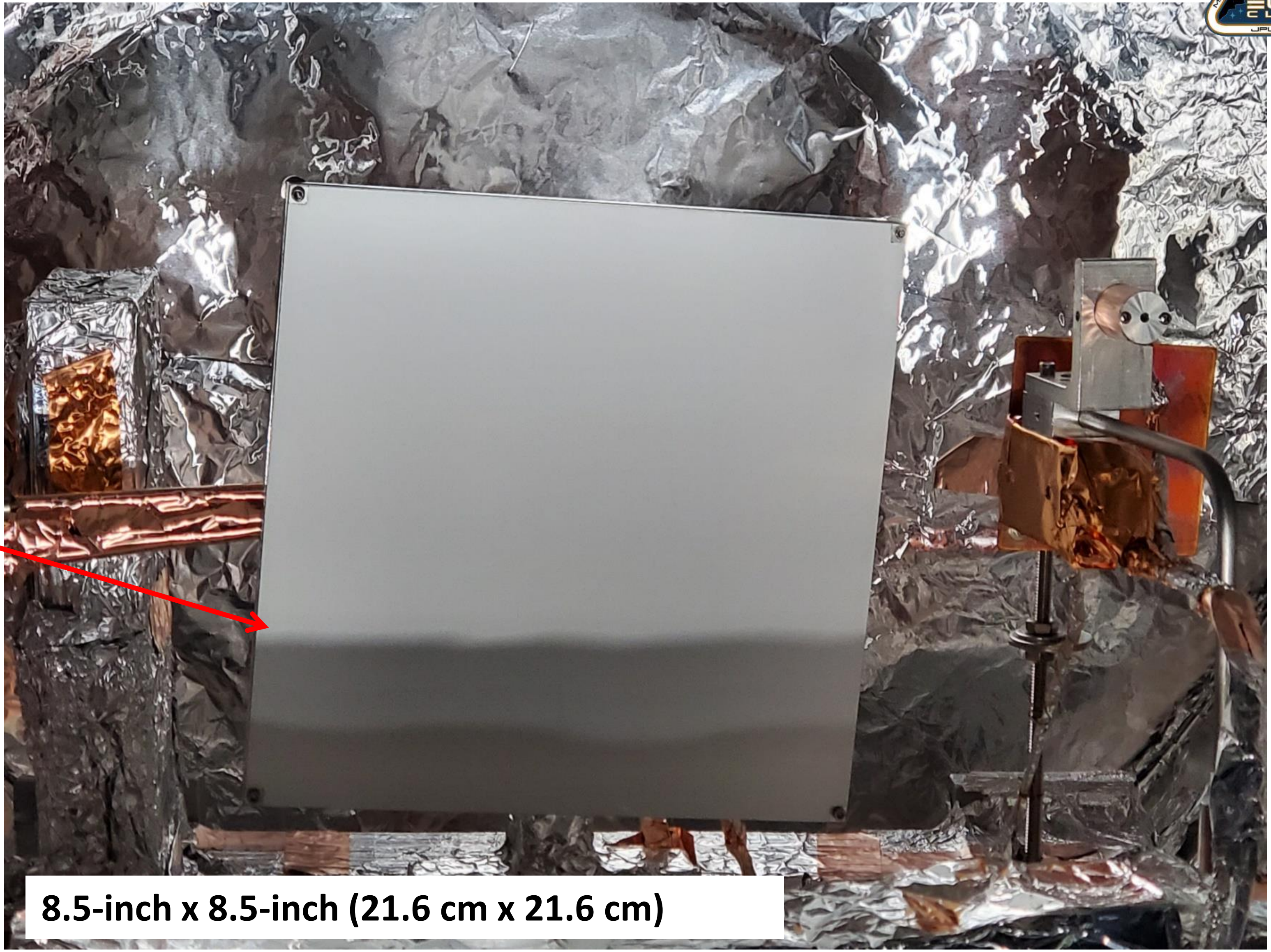
8.5-inch x 8.5-inch (21.6 cm x 21.6 cm) Z93C55

White Paint Sample

Shadow due to angle of light source and position of translation stage at bottom of chamber



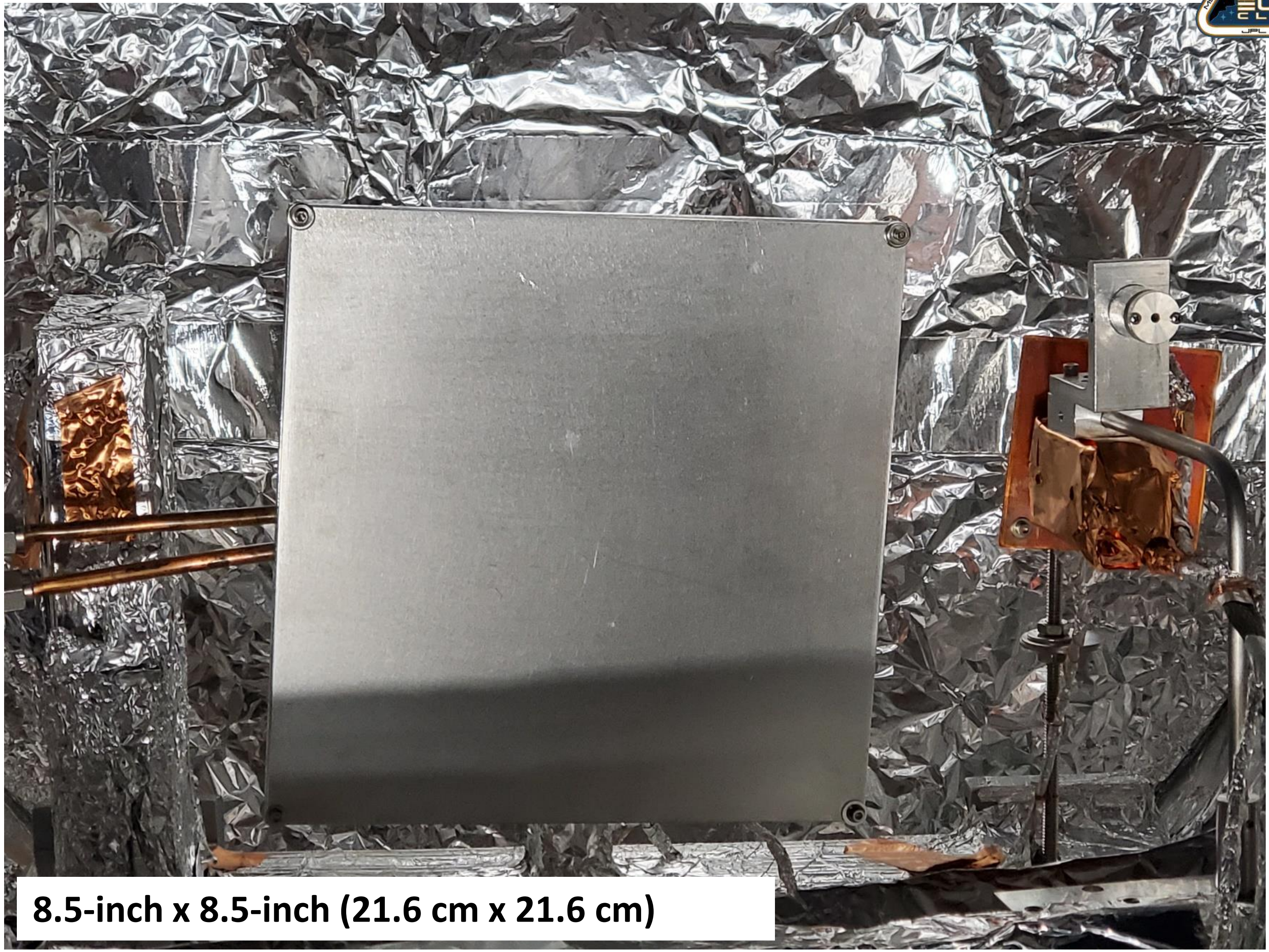
Credit: NASA/MSFC/T. Schneider

8.5-inch x 8.5-inch (21.6 cm x 21.6 cm)

Bare Aluminum Sample Used for "Empty Chamber" Test

So-called "Empty Chamber" tests were conducted to determine the noise floor and the waveform characteristics associated with spurious ESD events, i.e., discharges not occurring on the sample surface.

The "Empty Chamber" test samples were bare Aluminum



8.5-inch x 8.5-inch (21.6 cm x 21.6 cm)

Credit: NASA/MSFC/T. Schneider

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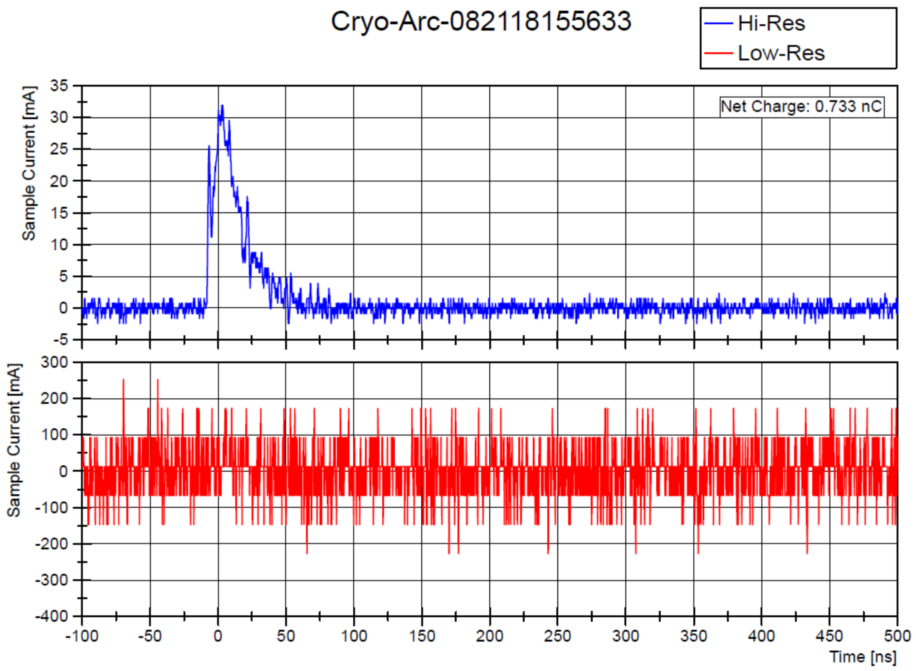
ESD Waveforms: Real vs. Spurious

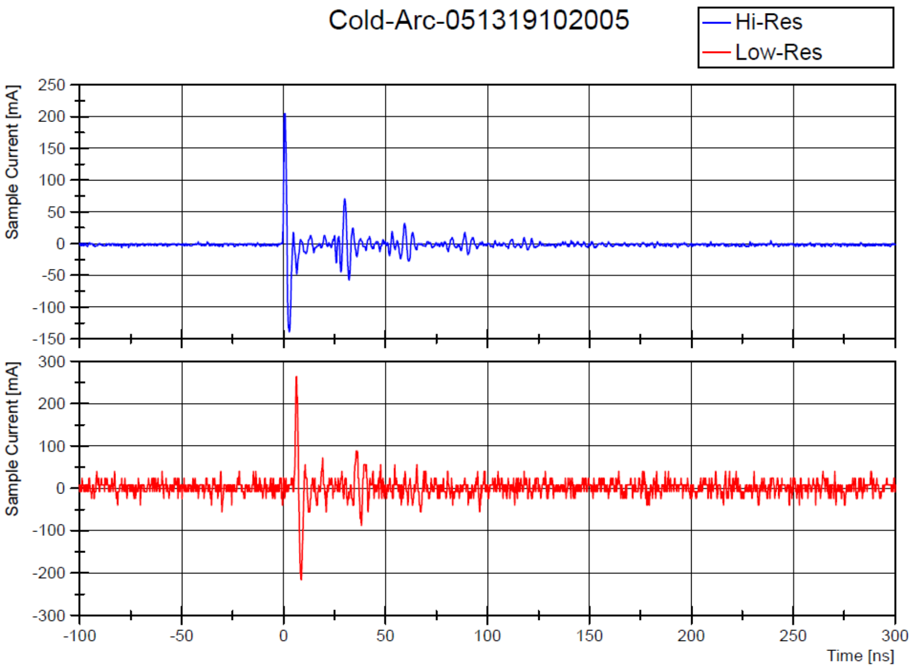
Genuine “Real” Discharge Waveform



Real Discharge Waveform

- Predominately positive-going current waveform with integrated net charge in the few hundred pico-coulomb range

Spurious Discharge Waveform

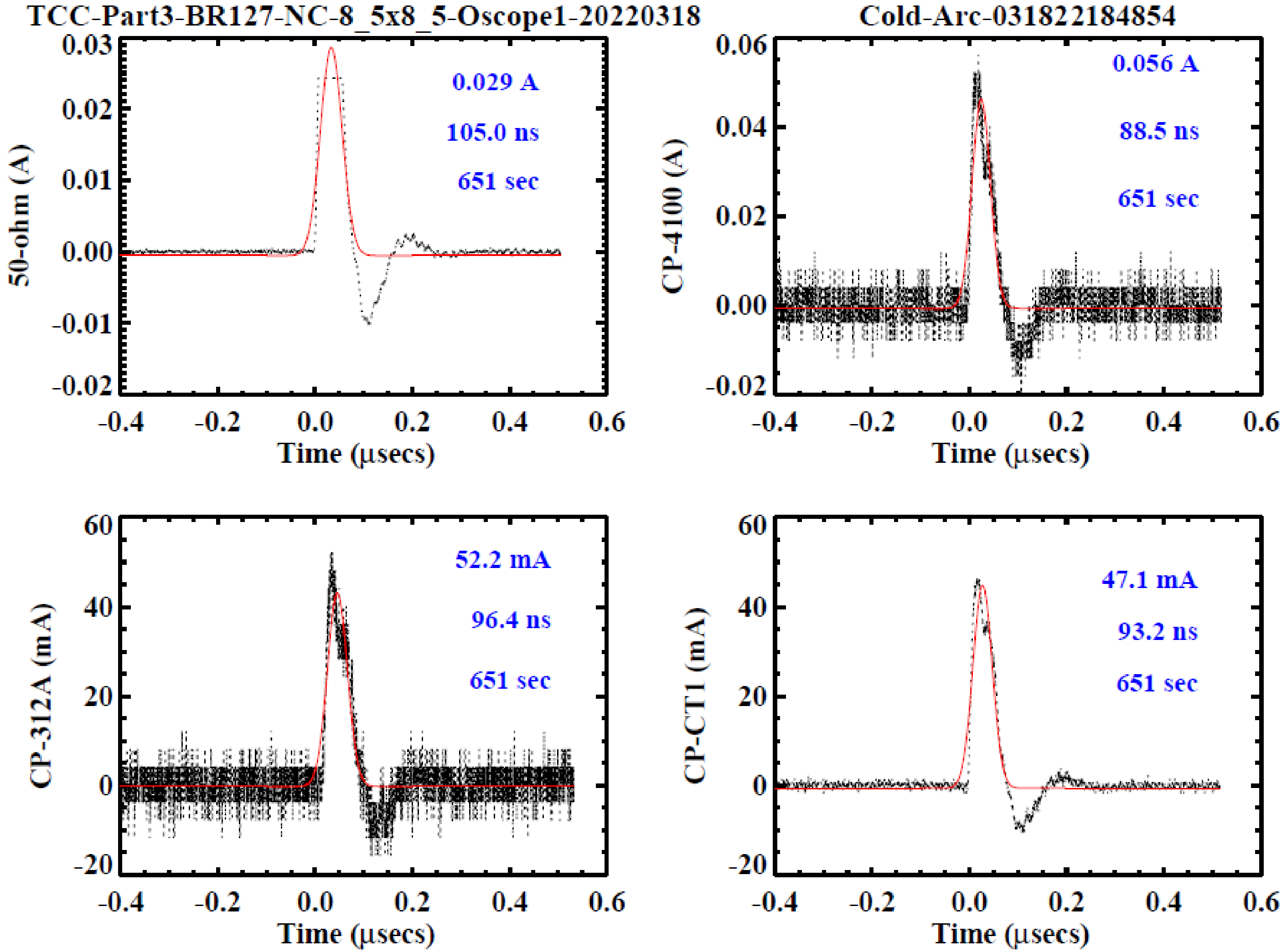


Spurious Discharge Waveform

- Numerous bi-polar (ringing) current waveforms with integrated net charge approximately zero or slightly negative

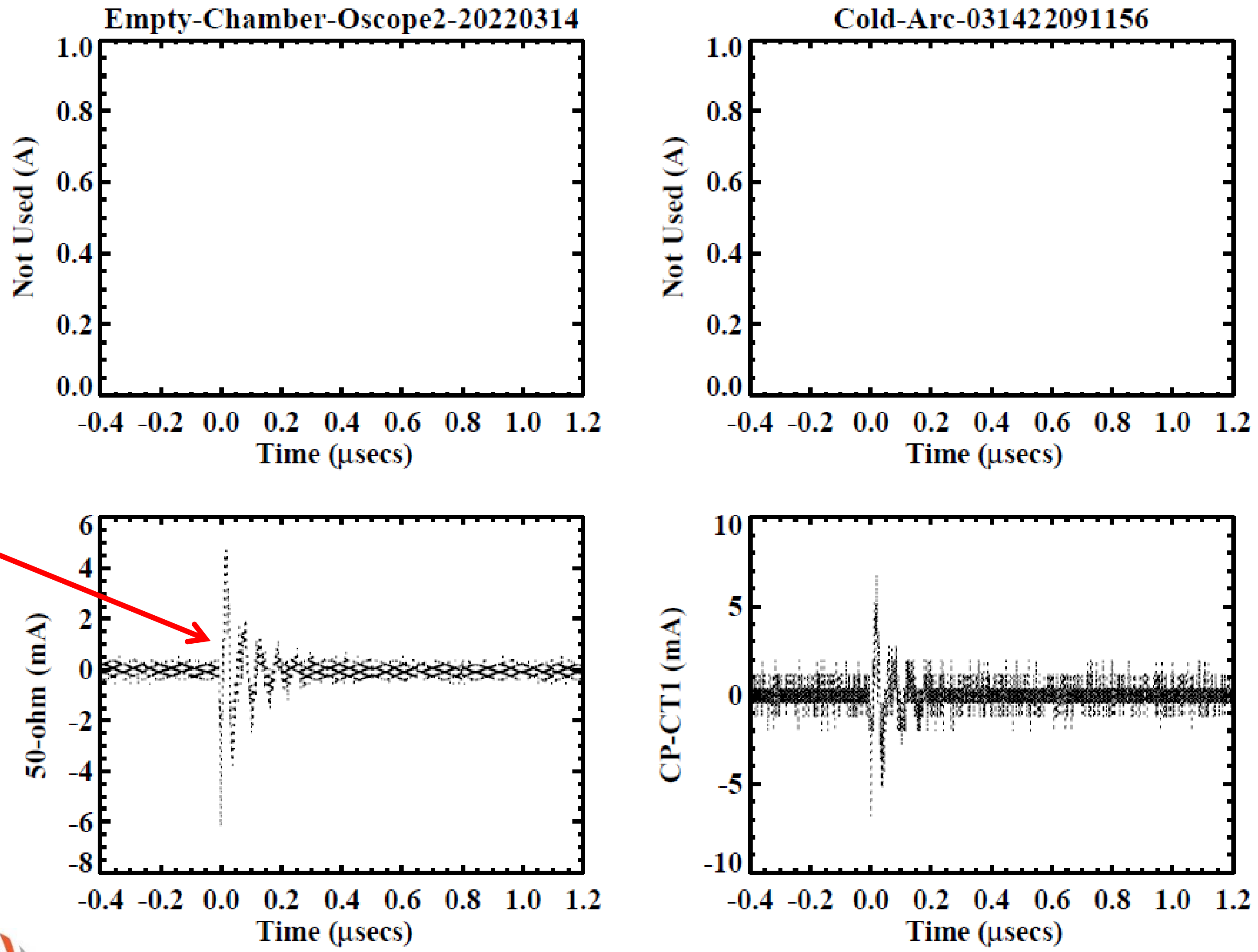
Example of Genuine Electrostatic Discharge on the Sample Surface

The positive-going signal suggests electrons leaving the sample and sourcing charge from the Aluminum substrate. Most likely an ESD event on the top surface of the sample.



Typical "Empty Chamber" Noise Waveform

Ringing and noisy waveform



Trend/Overview Analysis

Following a 10-hour test, the team found it was helpful to plot the Peak Current vs. Time from Start (of the electron exposure)

Trends in discharge polarity, maximum currents reached, and changes over time could be readily spotted

Data points included in the plot are selected based on maximum resolution without saturating the oscilloscope channel

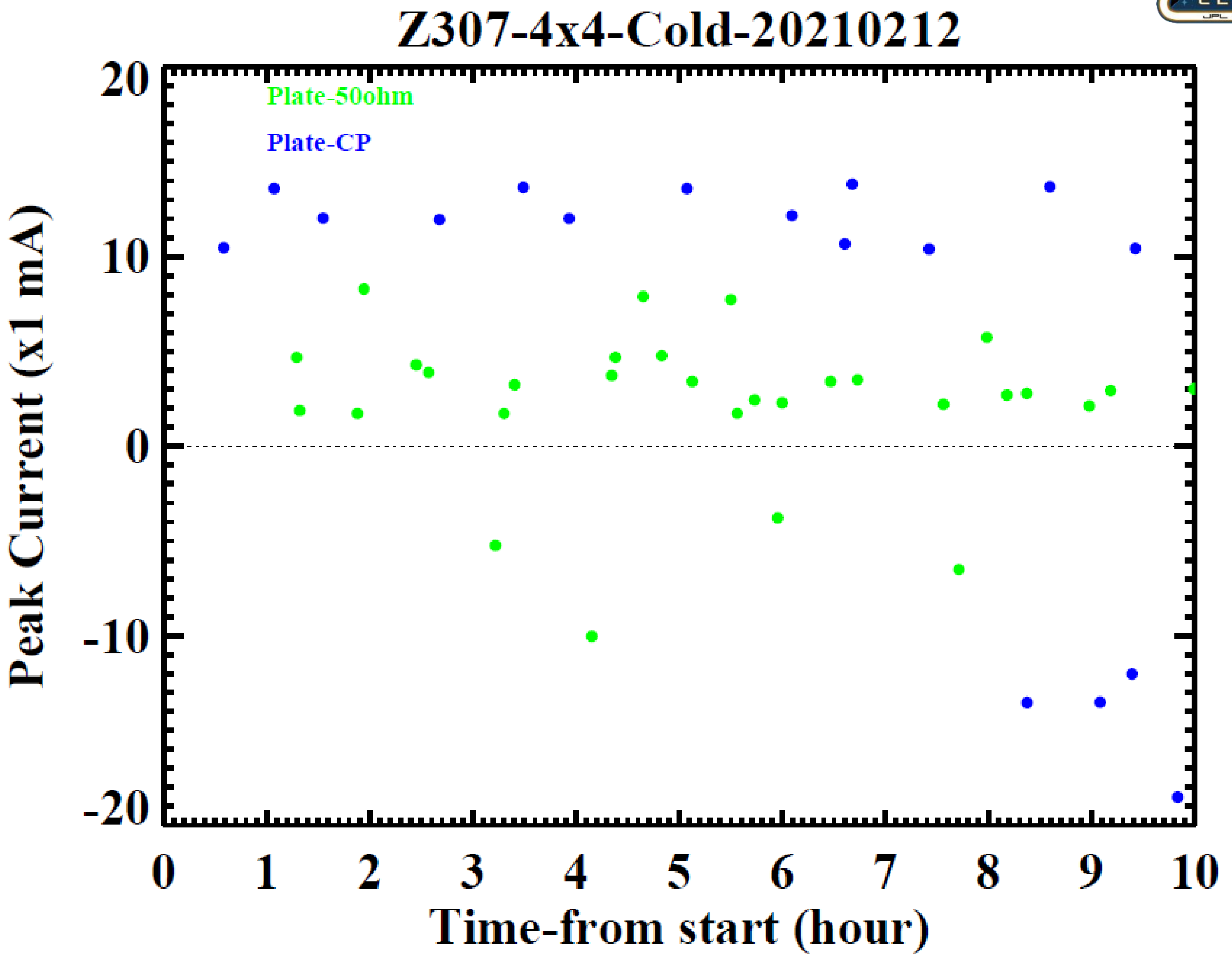


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Table of Samples with Descriptions

Designation	Color	Type	Manufacturer	Paint Thinner	Primer
AZ2000IECW	White	Inorganic	AZ Technology	None	Rub Prime
Z93C55	White	Inorganic	Alion Science & Tech	None	Rub Prime
Aptek 2719	White	Organic	Aptek Laboratories	20% Xylene	SS4155
Aptek Custom on Kapton	White	Organic	Aptek Laboratories	Proprietary	Proprietary
Aeroglaze Z307 V2	Black	Organic	Lord Corporation	None	4860-52
Aeroglaze Z307 V1	Black	Organic	Lord Corporation	None	9929 w/ C
MH55ICP	Black	Inorganic	Alion Science & Tech	None	Rub Prime
BR-127 NC/ESD	Black	Organic	Cytec Industries	None	None
Aptek 2555	Black	Inorganic	Aptek Laboratories	Proprietary	Proprietary
Aptek 2554 ESD	White	Inorganic	Aptek Laboratories	Proprietary	Proprietary

Listing of Coating and Charging Test Results

Material	Test #	Test Condition	Color	Temp (C)	Energy (keV)	Flux (nA/cm2)	# of Triggers	TREK Probe Extrema Value (kV)	Valid # of Sample Arcs*
AZ-2000 IECW	2	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.11	0
		10 hrs Cold		-170			9	-0.31	1
Aptek 2727	1	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	3	-0.97	0
		10 hrs Cold		-170	60	0.5	59	-4.78	25
Z-93C55	3	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.09	0
		10 hrs Cold		-170			0	-0.28	0
Aeroglaze Z307 VI	1	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.5	1	-0.12	0
		10 hrs Cold		-170			2	-0.32	0
Aptek Custom	3	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.04	0
		10 hrs Cold		-170			6	0.44	0
Aptek 2719	3	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.10	0
		10 hrs Cold		-170			69	-0.23	25
Aeroglaze Z307 VII	3	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	1	-0.17	0
		10 hrs Cold		-170			2	-0.43	1
MH55ICP	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.5	0	-0.08	0
		10 hrs Cold		-170			0	-0.28	0
Aeroglaze Z307 VIII	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	0	-0.17	0
		10 hrs Cold		-170			13	-0.49	2
BR-127NC ESD Primer	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	0	-0.12	0
		10 hrs Cold		-170			0	-0.32	0
Aeroglaze Z307 V4	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	0	-0.16	0
		10 hrs Cold		-170			11	-0.48	2
Aptek 2555	1	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.5	0	-0.15	0
		10 hrs Cold		-170			10	-0.35	1
Aptek 2554ESD	1	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.09	0
		10 hrs Cold		-170			20	0.2	1

Samples in red were removed from the candidate list due to discharge behavior or processing issues

Coatings with Optimum ESD Performance

Samples below exhibited zero valid arcs during the combined 14 hours of exposure

Material	Test #	Test Condition	Color	Temp (C)	Energy (keV)	Flux (nA/cm2)	# of Triggers	TREK Probe Extrema Value (kV)	Valid # of Sample Arcs*
Z-93C55*	3	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.09	0
		10 hrs Cold		-170			0	-0.28	0
Aptek Custom	3	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.04	0
		10 hrs Cold		-170			6	0.44	0
MH55ICP	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.5	0	-0.08	0
		10 hrs Cold		-170			0	-0.28	0
BR-127NC ESD Primer	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	0	-0.12	0
		10 hrs Cold		-170			0	-0.32	0
Aeroglaze Z307 VI	1	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.5	1	-0.12	0
		10 hrs Cold		-170			2	-0.32	0

* Process development necessary for Z-93C55 use

Screening Coating Performance

- **Samples with zero valid arcs are considered a PASS**
- **Samples with few, small arcs require further testing**

Material	Test #	Test Condition	Color	Temp (C)	Energy (keV)	Flux (nA/cm2)	# of Triggers	TREK Probe Extrema Value (kV)	Valid # of Sample Arcs*
Aeroglaze Z307 VII	3	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	1	-0.17	0
		10 hrs Cold		-170			2	-0.43	1
Aeroglaze Z307 VIII	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	0	-0.17	0
		10 hrs Cold		-170			13	-0.49	2
Aeroglaze Z307 V4	2	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.72	0	-0.16	0
		10 hrs Cold		-170			11	-0.48	2
Aptek 2555	1	4 hrs RT	Black	25 ≤ T ≤ 30	60	0.5	0	-0.15	0
		10 hrs Cold		-170			10	-0.35	1
Aptek 2554ESD	1	4 hrs RT	White	25 ≤ T ≤ 30	60	0.5	0	-0.09	0
		10 hrs Cold		-170			20	0.2	1

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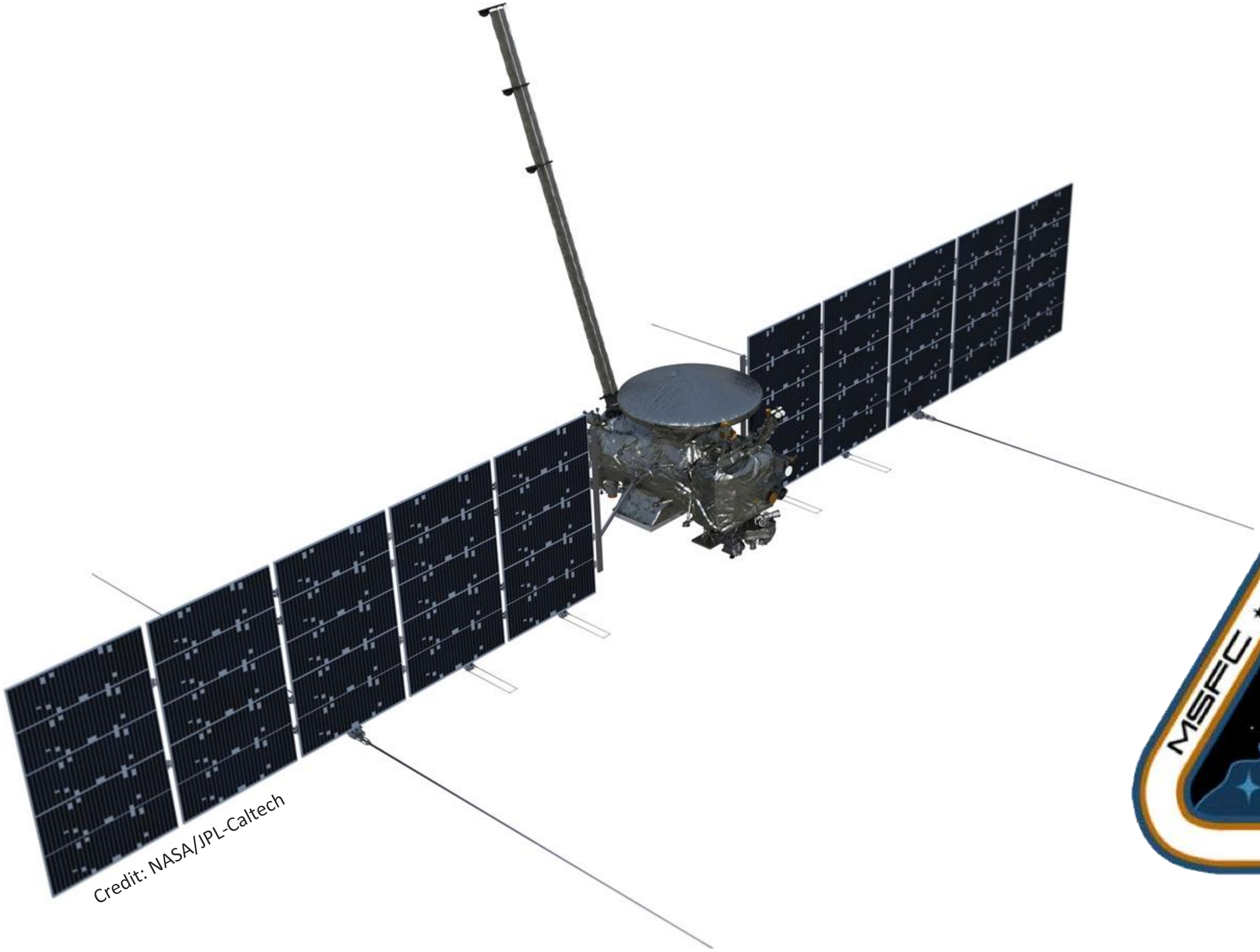
Summary

- A Thermal Control Coating (TCC) Charging Test Campaign has been undertaken to find coatings that meet the challenging spacecraft charging environment associated with the Jovian system
  - Key focus was encounters with the moon Europa
- Initial screening of candidate coatings showed overall good Electrostatic Discharge (ESD) performance.
  - Typical peak current magnitudes were in the low 10’s of milliamps.
- The low peak current magnitude forced the MSFC team to improve their chamber’s ESD cleanliness
  - Added conductive foils and tapes in areas of the chamber near the sample location
  - Implemented “Empty Chamber” tests using bare Aluminum samples to establish the noise floor and the waveform characteristics associated with spurious discharges
- To make a final determination on the usage of a coating that generated a modest number of discharges, an area scaling test was conducted to ensure the magnitude and frequency of the discharges did not scale with area
  - None of the coatings exhibited a direct correlation in peak current as a function of area
- **In the end, the JPL team was able to down select to a set of coatings that met their thermal and ESD performance metrics**



Credit: NASA's Jet Propulsion Lab

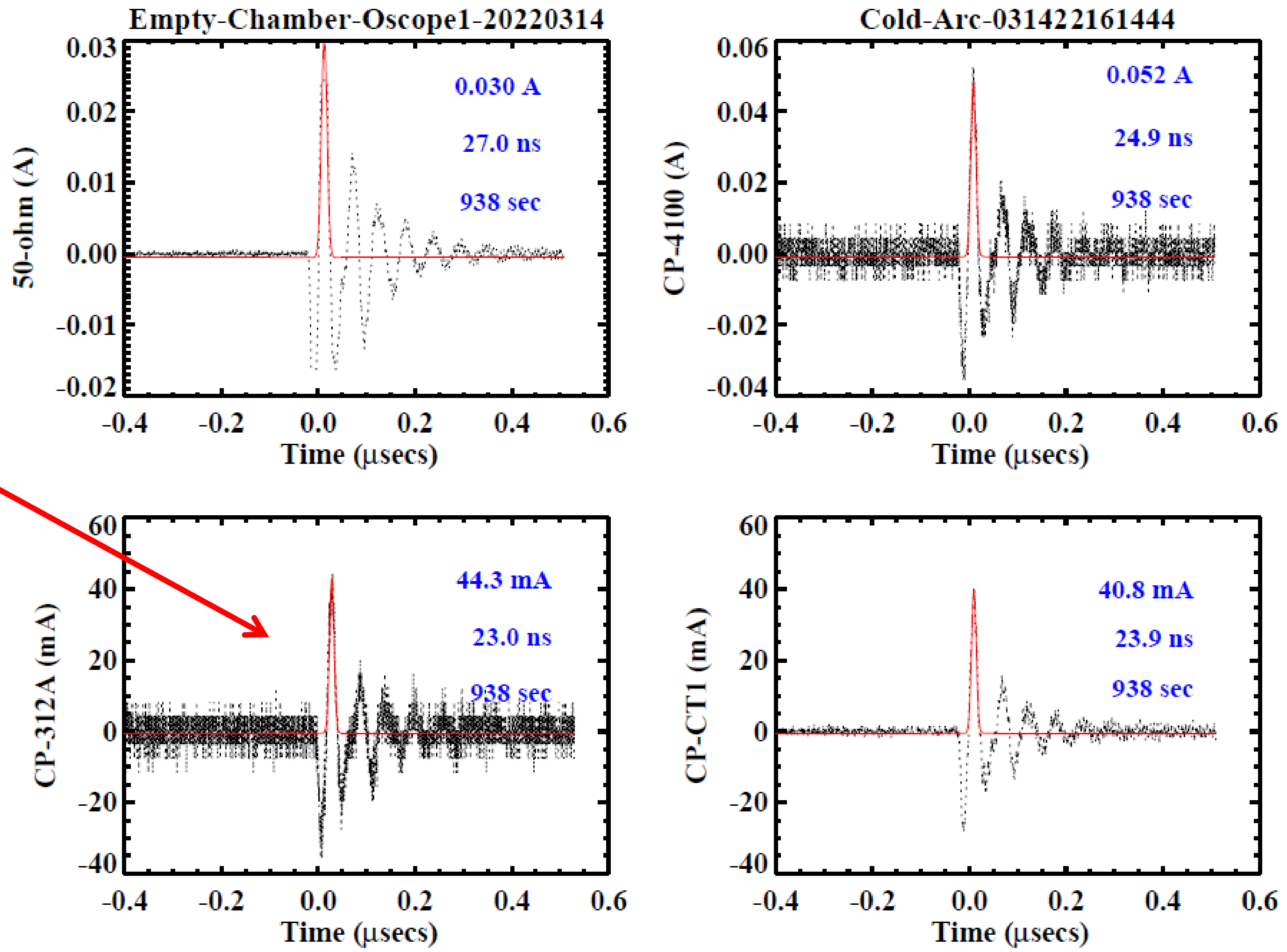
Launch Target: October 2024 with Jupiter Orbit Insertion in 2030

Back-up Charts

Extra Examples and Pictures

Typical Empty Chamber Noise Waveform

Peak magnitude a bit high, but it is clearly part of a ringing noise waveform



View From Behind 8.5-inch x 8.5-inch (21.6 cm x 21.6 cm) Sample

TCC Charging Test Phase 3 (March 2022)

Credit: NASA/MSFC/T. Schneider